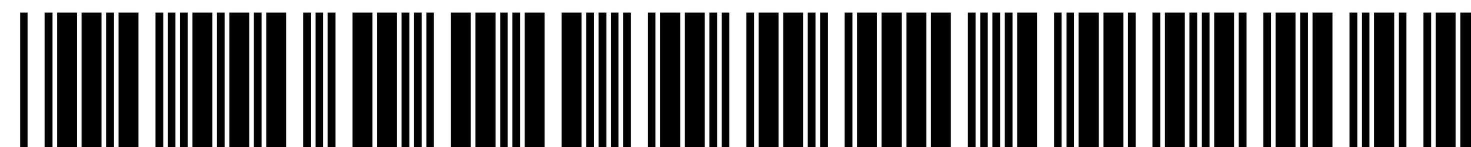

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(54) **METHOD OF FORMING MULTILAYERED CONDUCTIVE LAYERS FOR SEMICONDUCTOR DEVICE**

(75) Inventor: **Tetsuo Usami**, Tokyo (JP)

(73) Assignee: **Oki Electric Industry Co., Ltd.**, Tokyo (JP)

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(30) **Foreign Application Priority Data**

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(52) **U.S. Cl.** **438/660**; 438/653; 438/927; 257/767; 257/751; 257/486

(58) **Field of Search** 438/660–663, 438/653, 643, 627, 927; 257/750–753, 765, 486, 450, 376, 17, 767

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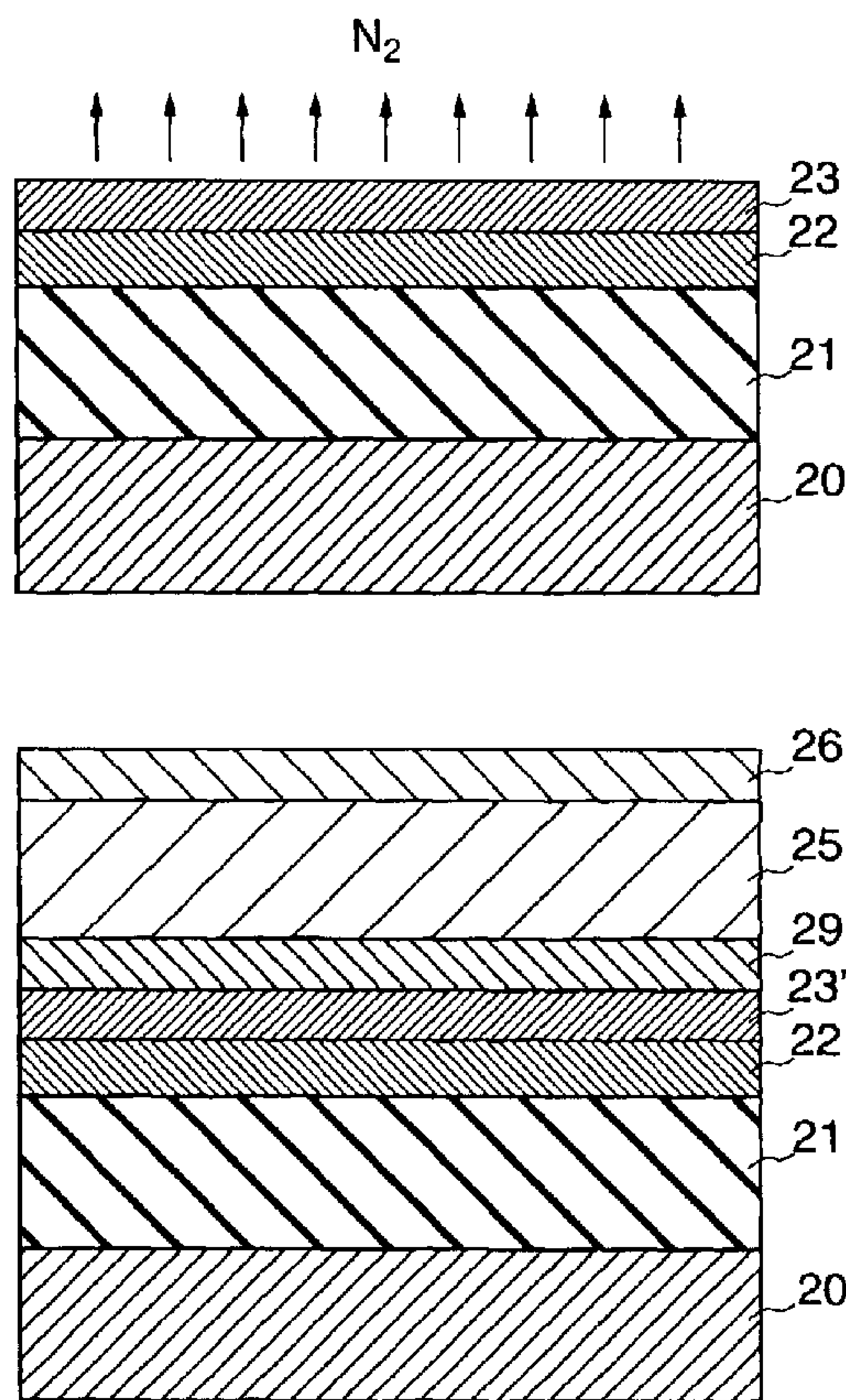
Primary Examiner—Matthew Smith
Assistant Examiner—Lee Calvin
(74) *Attorney, Agent, or Firm*—Volentine Francos, PLLC

(57) **ABSTRACT**

A method of manufacturing a semiconductor device including forming an insulator layer on an integrated circuit, forming a barrier layer having a first titanium film and a titanium nitride film on the insulator layer, heat-treating the barrier layer to release nitrogen gas from the titanium nitride film, forming a second titanium film on the barrier layer, and forming an aluminum film used as a wired metal on the second titanium film.

15 Claims, 4 Drawing Sheets



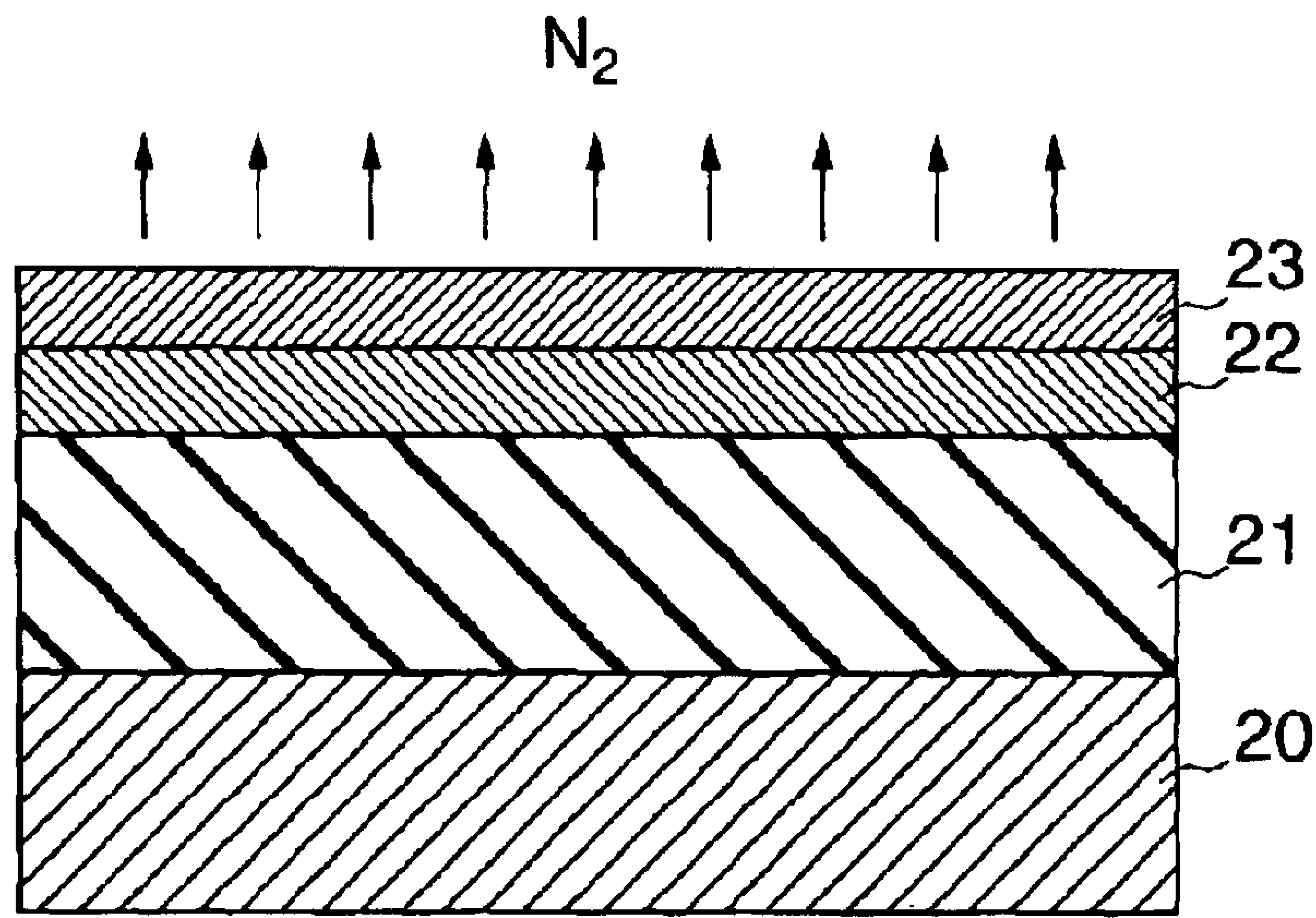


Fig. 1(a)

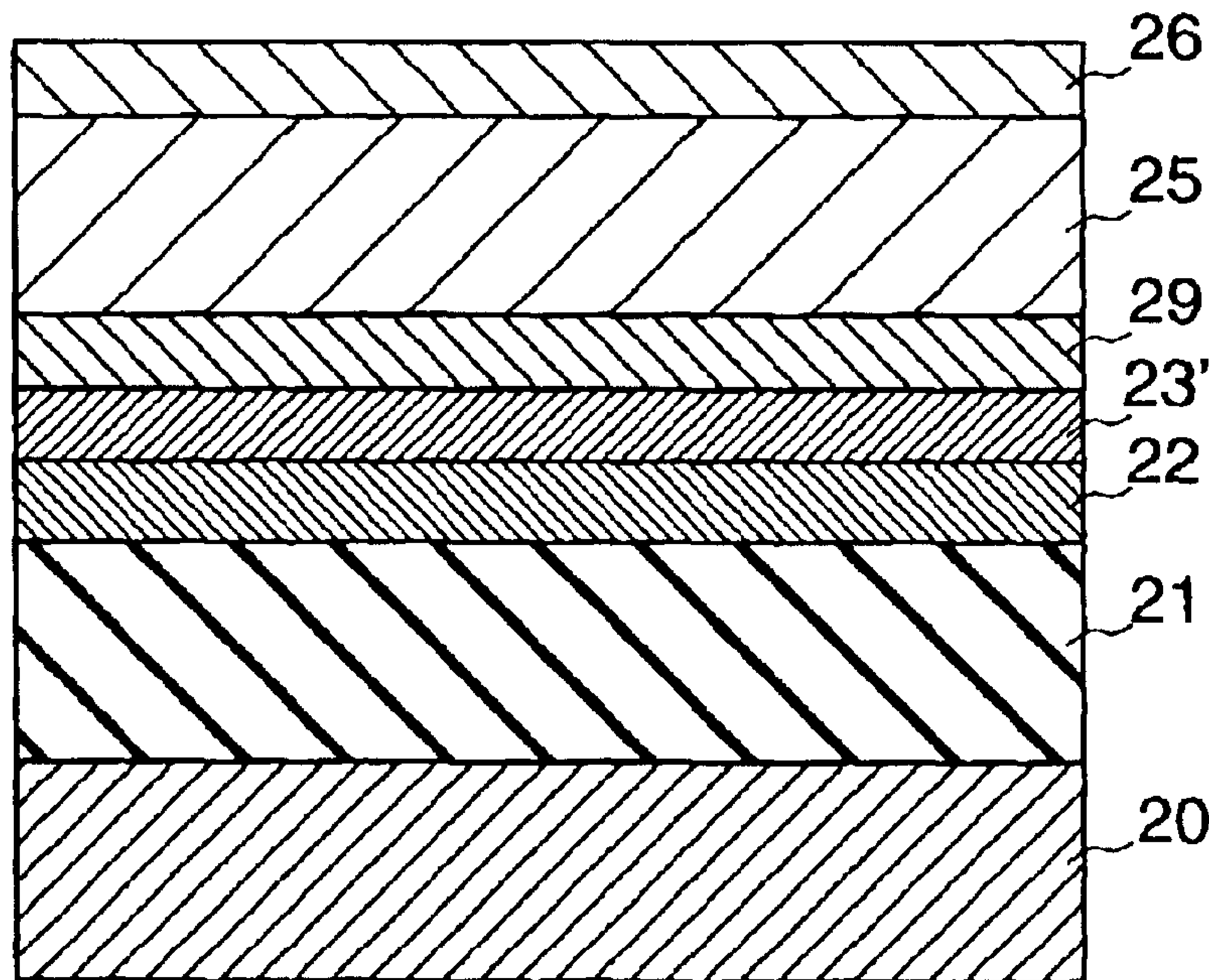


Fig. 1(b)

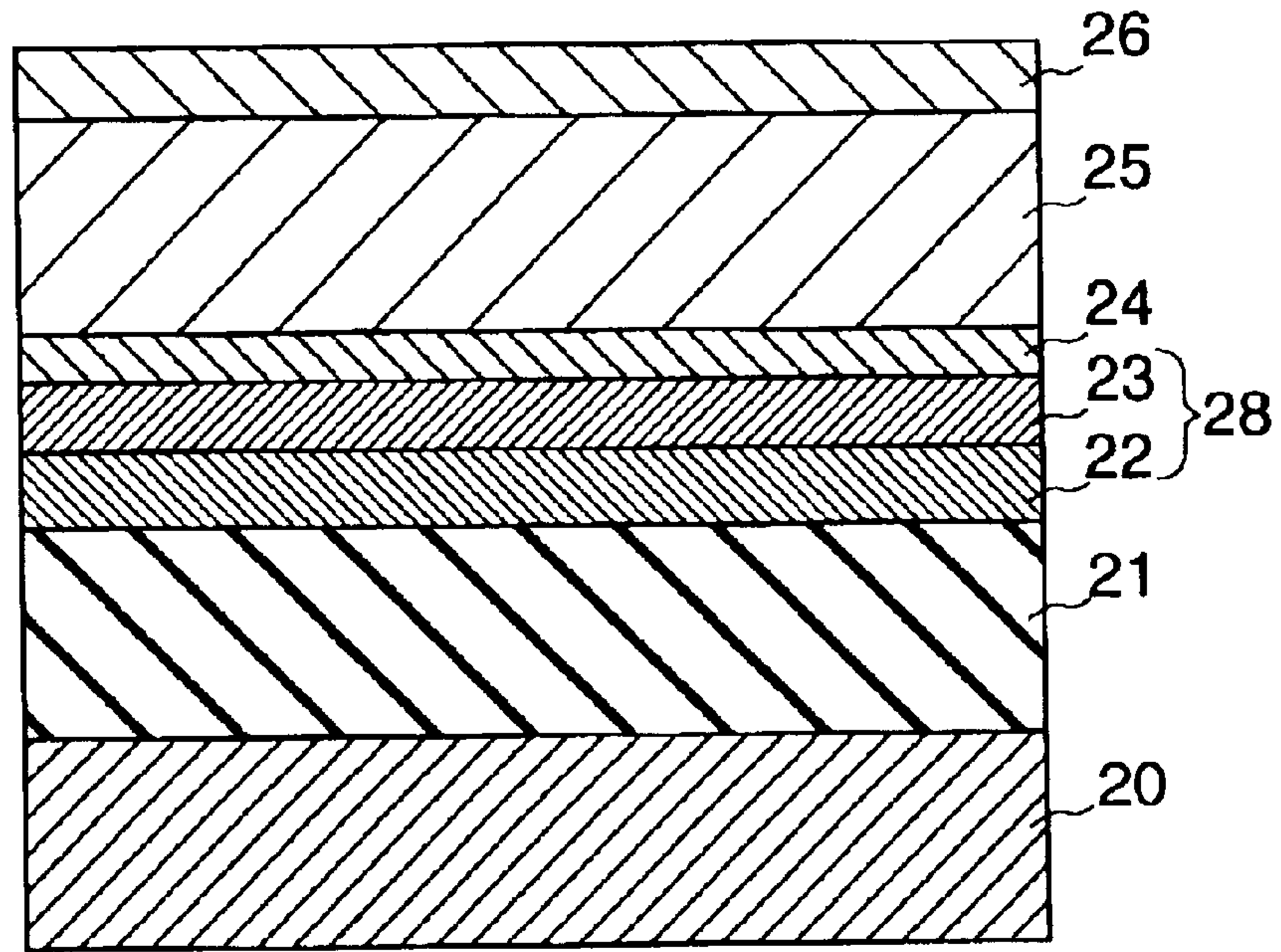


Fig. 2

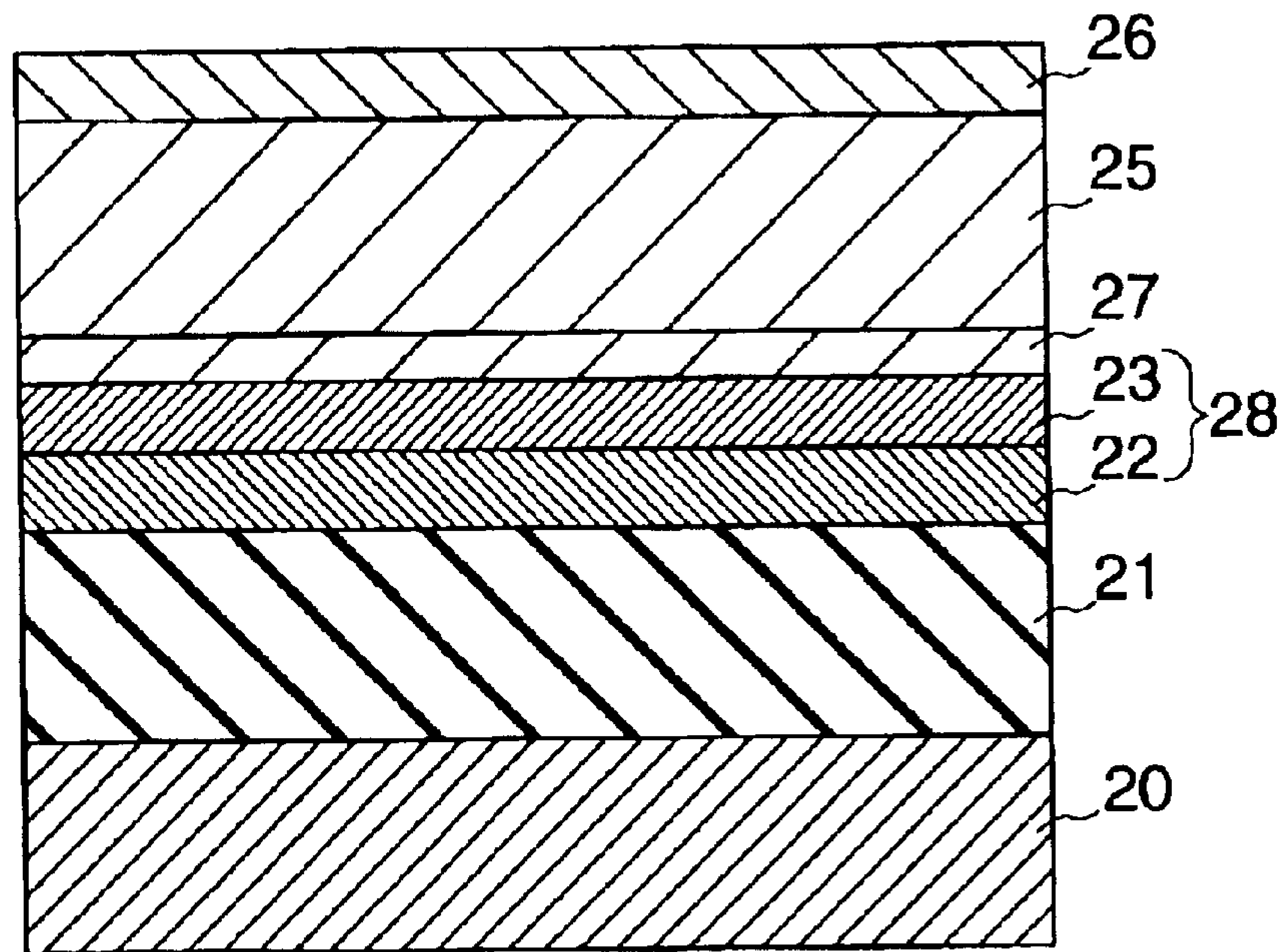


Fig. 3

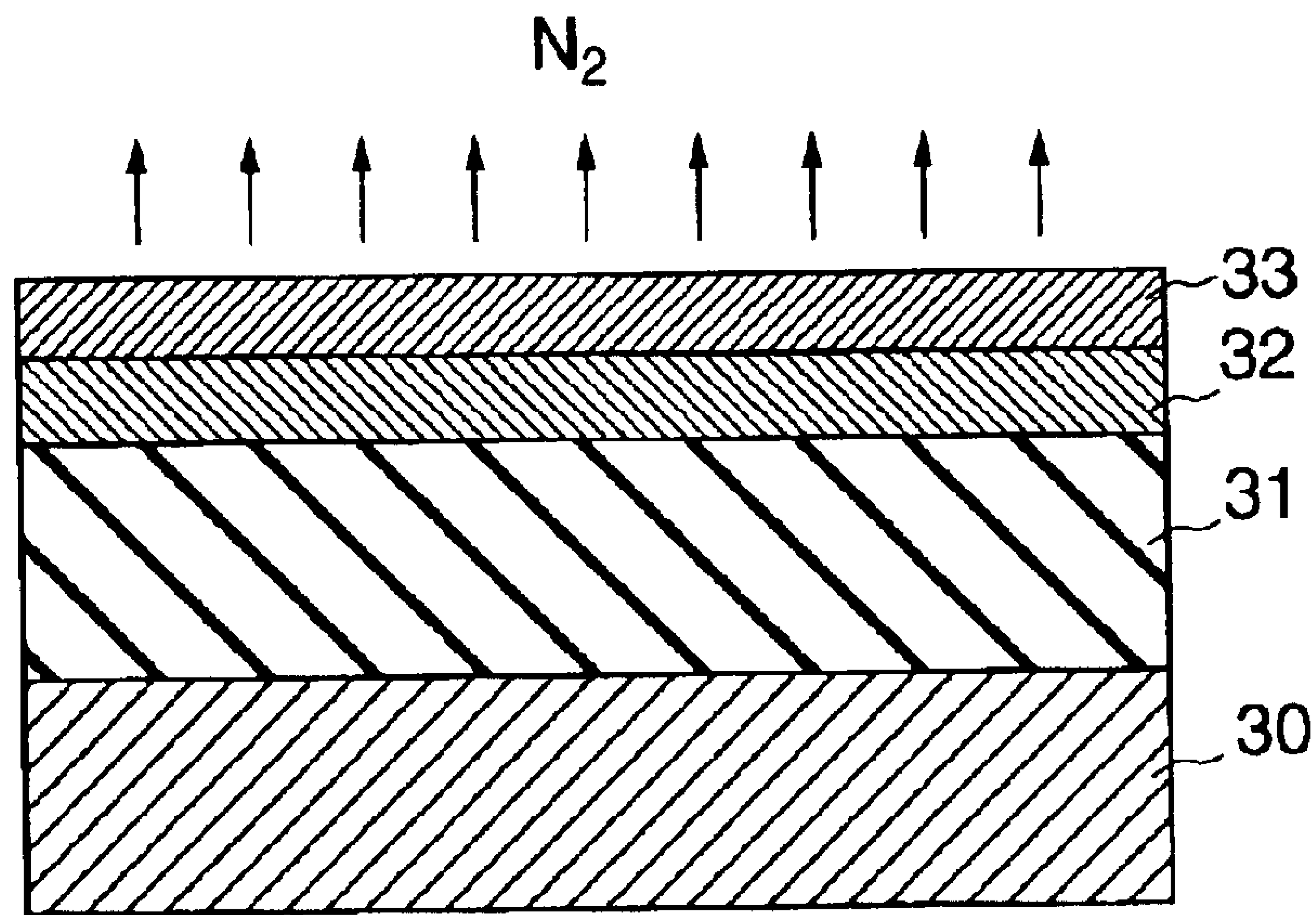


Fig. 4(a)

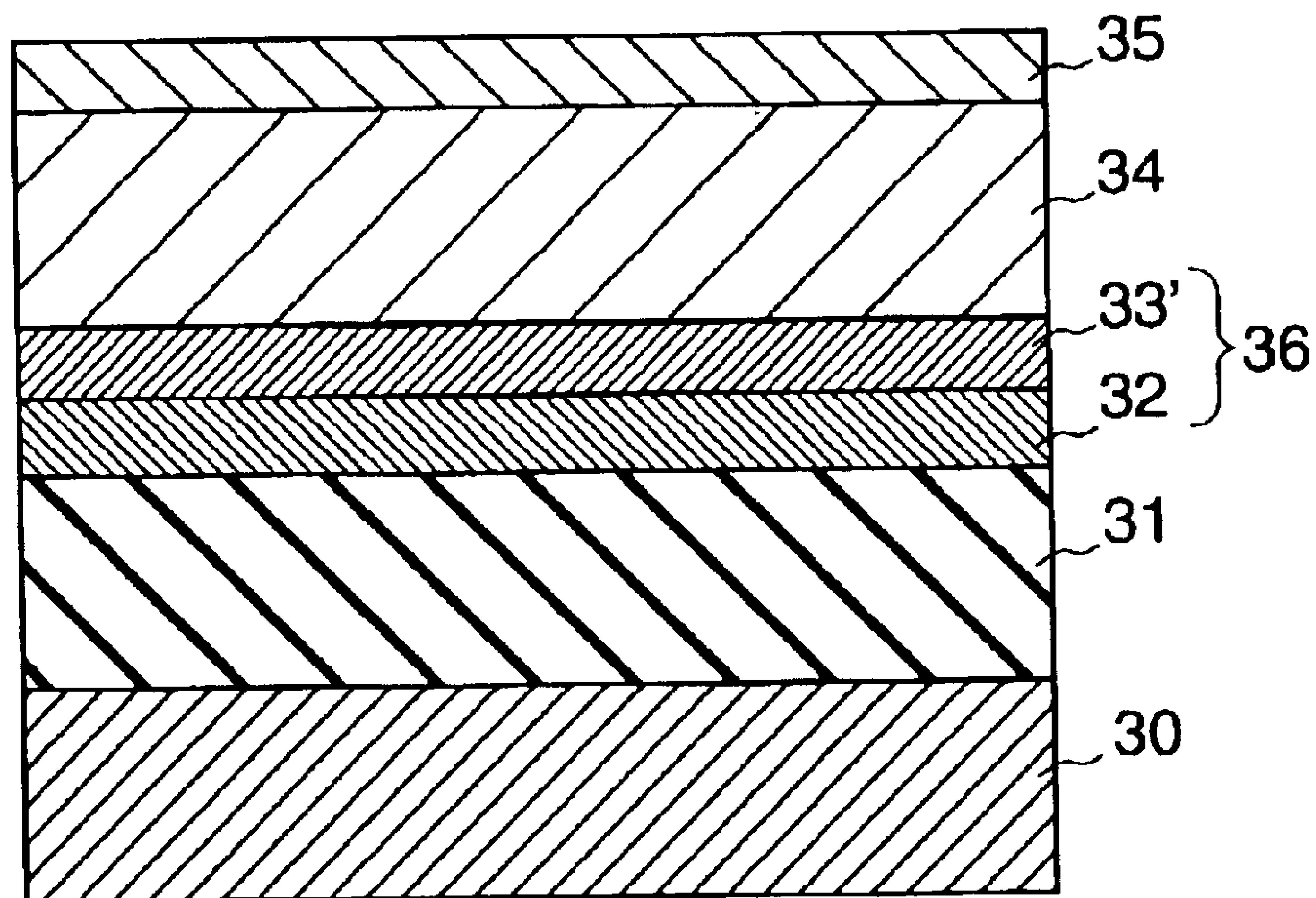


Fig. 4(b)

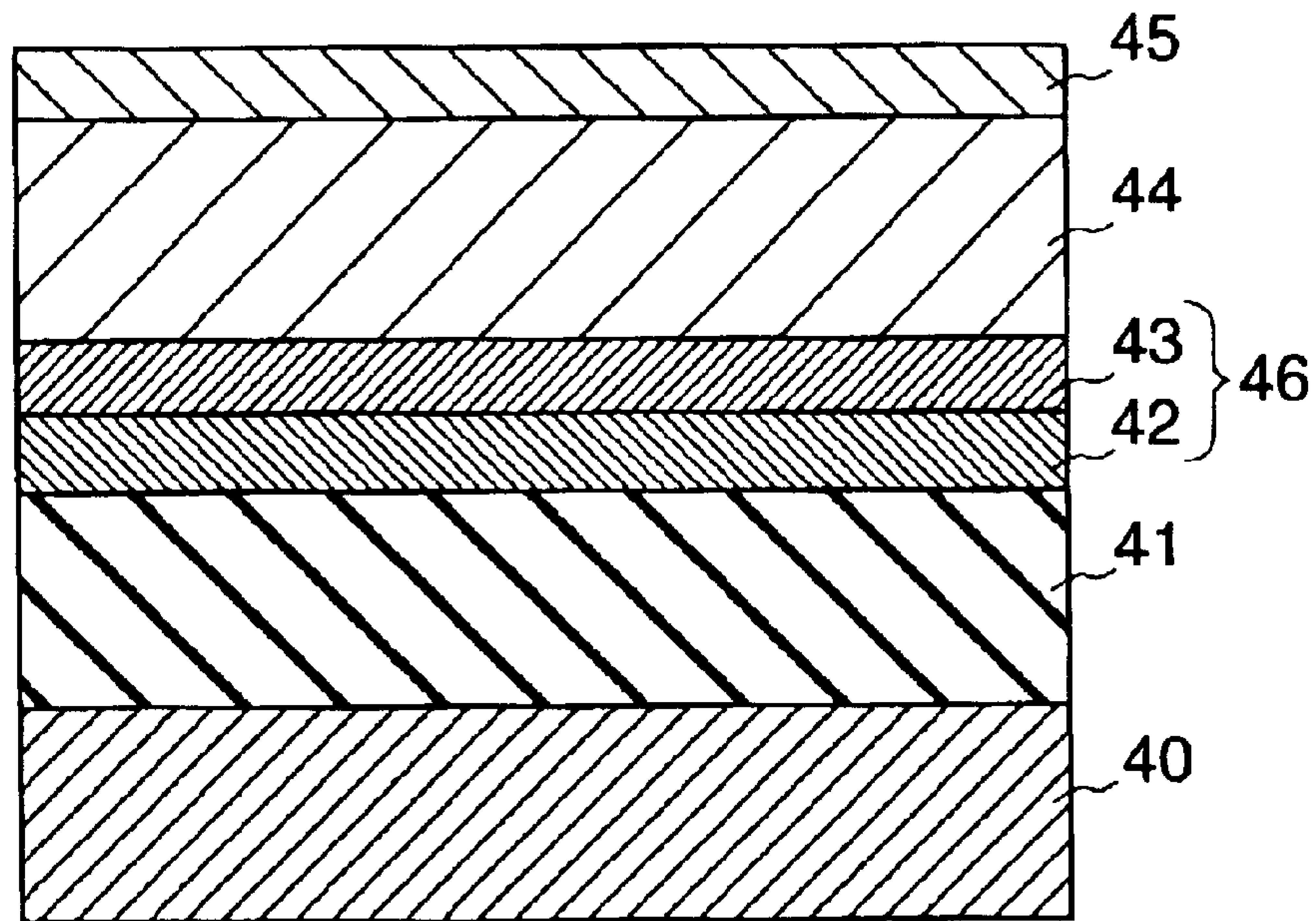


Fig. 5

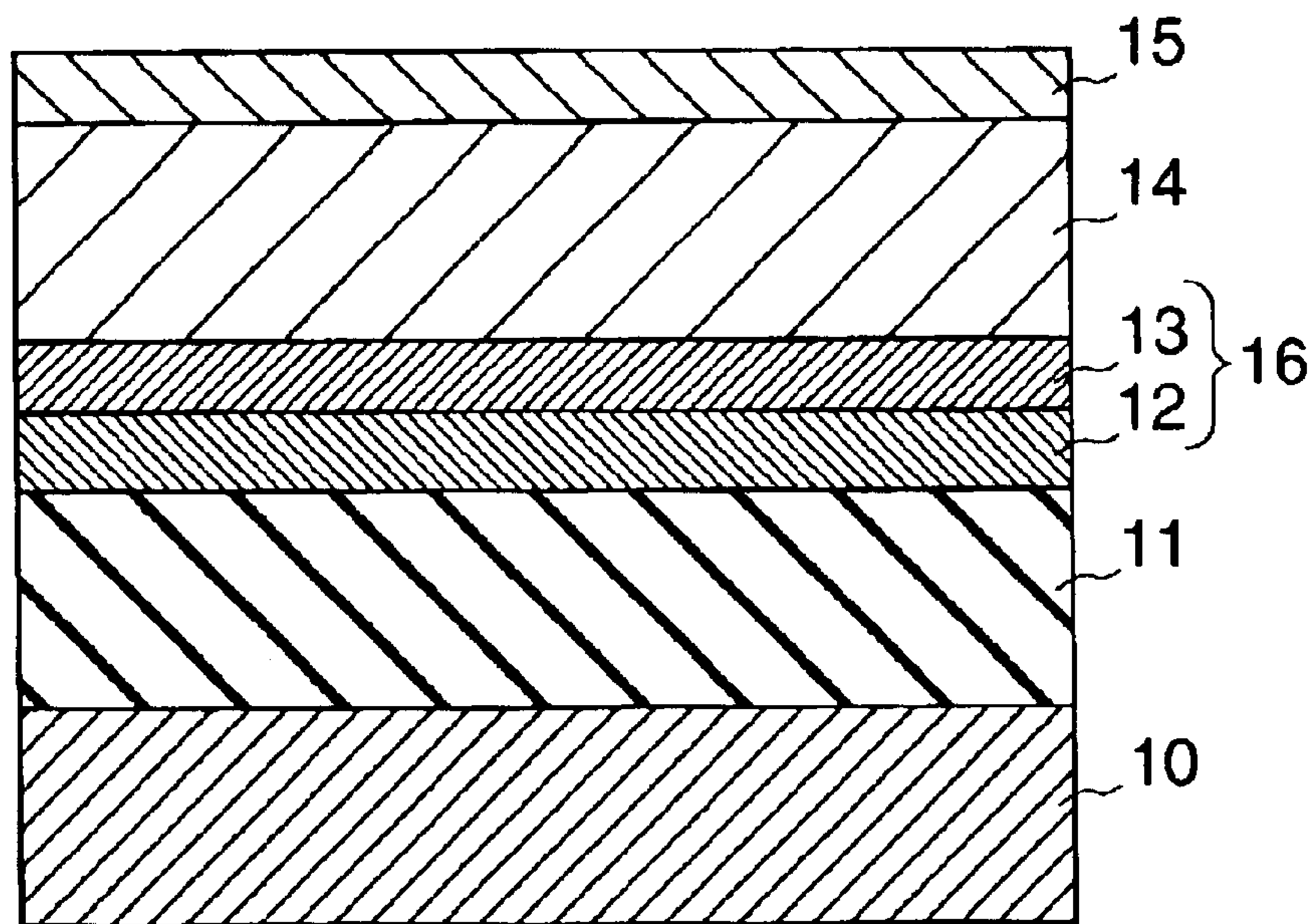


Fig. 6 Prior Art

METHOD OF FORMING MULTILAYERED CONDUCTIVE LAYERS FOR SEMICONDUCTOR DEVICE

BACKGROUND OF THE INVENTION

The present invention relates to a semiconductor device and a method of manufacturing the same, and particularly to a method of forming a multilayered conductive layer for a semiconductor device, which improves electromigration resistance.

A conventional multilayered conductive layer configuration employed in a semiconductor device is generally illustrated as a sectional structure shown in FIG. **6**. An aluminum (Al) film **14** as a conductive layer is used, and a titanium (Ti) film **12** and a titanium nitride (TiN) film **13** provided on the Ti film **12** are used as a barrier layer **16** on an insulator layer **11** deposited on an integrated circuit **10**, so as to avoid a conductive layer-to-layer leak developed by diffusion of Al thereof into an insulating film. Now, the Ti film is effective in improving the quality of an Al film, principally, its orientation, and an improvement in the orientation of the Al film provides the effect of enhancing electromigration resistance. This electromigration (EM) is a phenomenon in which atoms are moved by the flow of a current. Since it produces a failure such as breaking of a conductive layer, an improvement in EM resistance is essential to the enhancement of reliability. Further, the TiN film **13** is needed to prevent the reaction of the Ti film and the Al film for the wired metal.

Next, the Al film **14** used as the wired metal is deposited by heating at 200° C. to 400° C. The reason why heating is made upon the formation of the Al film, is to make an Al grain large by heating to enhance the EM resistance and to improve step coverage (state of a film deposited on a step) in a contact hole. The migration has been considered to take place along a grain boundary. Since the grain boundary is reduced if the Al grain is relatively set larger than a conductive layer width, the electromigration (EM) can be restrained.

Thereafter, Ti, TiN, or a laminated layer of Ti and TiN, for example is deposited as an antireflection film (ARM) **15** relative to an Al surface based on a photolithography process. Further, the so-deposited film is subjected to a photolithography process and an etching process and then to patterning, whereby each of conductive layers is formed.

In the above method on the other hand, since the Al film **14** is deposited at the high temperature of from 200° C. to 400° C. upon deposition thereof after the formation of the TiN film **13**, nitrogen gas (N_2 gas) is released from the surface of the TiN film **13** and from within the TiN film **13** to within an Al deposition chamber, so that N_2 is brought into the Al film **14**. It has generally been known that the mixing of N_2 gas upon Al deposition interferes with the growth of a grain and hence EM resistance is degraded. Thus, the present method had a problem that reliability was degraded.

SUMMARY OF THE INVENTION

The present invention has been made in view of the above problem involved in the conventional semiconductor device and semiconductor device manufacturing method, particularly, the method of forming the multilayered conductive layer for the semiconductor device. It is an object of the present invention to provide a novel and improved semiconductor device and a method of manufacturing the semiconductor device, which are capable of preventing N_2

from being captured during the deposition of a conductive layer Al film and enhancing electromigration resistance.

The present invention provides a method of manufacturing a semiconductor device, comprising, forming an insulator layer on an integrated circuit, forming a barrier layer comprised of a first titanium film and a titanium nitride film on the insulator layer, heat-treating the barrier layer to release nitrogen gas from the titanium nitride film, forming a second titanium film on the barrier layer, and forming an aluminum film used as a wired metal on the second titanium film.

BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention, it is believed that the invention, the objects and features of the invention and further objects, features and advantages thereof will be better understood from the following description taken in connection with the accompanying drawings in which:

FIG. **1**(*a*) is a process sectional view showing a multilayered conductive layer structure of a semiconductor device according to a first embodiment of the present invention, subsequent to the discharge of N_2 gas after the deposition of a TiN film;

FIG. **1**(*b*) is a process sectional view showing the multilayered conductive layer structure of the semiconductor device according to the first embodiment of the present invention, subsequent to the formation of a Ti film, an Al film and an antireflection film after the discharge of the N_2 gas;

FIG. **2** is a cross-sectional view showing a multilayered conductive layer structure of a semiconductor device according to a second embodiment of the present invention;

FIG. **3** is a cross-sectional view illustrating a multilayered conductive layer structure of a semiconductor device according to a third embodiment of the present invention;

FIG. **4**(*a*) is a process sectional view showing a multilayered conductive layer structure of a semiconductor device according to a fourth embodiment of the present invention, subsequent to the discharge of N_2 gas after the deposition of a TiN film;

FIG. **4**(*b*) is a process sectional view illustrating the multilayered conductive layer structure of the semiconductor device according to the fourth embodiment of the present invention, subsequent to the formation of an Al film and an antireflection film after the discharge of the N_2 gas;

FIG. **5** is a cross-sectional view depicting a multilayered conductive layer structure of a semiconductor device according to a fifth embodiment of the present invention; and

FIG. **6** is a cross-sectional view showing a multilayered conductive layer structure of a semiconductor device according to a related art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of semiconductor devices according to the present invention, and methods of manufacturing the semiconductor devices will hereinafter be described in detail with reference to the accompanying drawings. Elements of structure having substantially the same functional configurations in the present specification and the drawings are respectively identified by the same reference numerals and the description of certain common elements will therefore be omitted.

First Embodiment

A process sectional view for describing a first embodiment of the present invention is shown in FIG. **1**. An insulator layer **21** is first formed on an integrated circuit **20**. Next, a Ti film **22** and a TiN film **23**, which serve as a barrier layer, are respectively successively deposited over the insulator layer **21** with a thickness of about 30 nm and a thickness of about 20 nm. Now the deposition of the respective films employed in the present embodiment is all carried out using a multichamber sputtering apparatus. The Ti film **22** serves as a barrier for preventing Al for a wired metal to be formed later from diffusing into the insulator layer **21**, whereas the TiN film **23** prevents the Ti film **22** and an Al film **25** from reacting with each other.

Thereafter, a wafer is heated at about 350° C. corresponding to a temperature greater than or equal to a temperature for the deposition of the conductive layer Al film for 60 seconds or more within a processing chamber in which the wafer is heated to a high temperature, thereby releasing N_2 gas from the surface of the TiN film **23** and from within the TIN film **23**. The result thereof is shown in FIG. **1**(*a*). Owing to the release of the N_2 gas, the TiN film **23** results in a TiN film **23'** whose surface layer portion is low in nitrogen concentration. A Ti film **29**, which is a few ten Å (Angstroms) or so, is further deposited on a barrier layer formed of the Ti film **22** and the TiN film **23'** in this way. The Ti film **29** per se nitrizes and absorbs the nitrogen gas N_2 discharged from the TiN film **23'** upon the subsequent formation of conductive layer Al film **25**.

Next, the wired Al film **25** is heated at about 225° C. to increase an Al grain and enhance EM resistance, so that it is deposited or grown so as to range from 400 nm to 600 nm in thickness. Thereafter, an antireflection film (ARM) **26** relative to an Al surface based on a photolithography process for forming micro patterns is formed on the Al film **25** with a thickness of about 70 nm. The result thereof is shown in FIG. **1**(*b*). As the antireflection film, may preferably be, for example, a Ti single layer, a TiN single layer or a laminated layer of Ti and TiN. Further, the so-formed film is subjected to a photolithography process and an etching process and then to patterning, whereby each of conductive layers is formed.

According to the first embodiment as described above, a TiN film is deposited and thereafter a wafer is heated at a temperature greater than or equal to an Al deposition temperature within a processing chamber in which the wafer is heated at a high temperature, to release N_2 gas from the TiN film in advance, whereby a TiN film whose surface layer portion is low in nitrogen concentration, is formed. Further, a thin Ti film per se, which nitrizes and absorbs N_2, is formed on the TiN film. Consequently, N_2 gas heated to a high temperature upon Al deposition and discharged from the TiN film is prevented from floating in an Al deposition chamber. It is thus possible to prevent N_2 from being mixed into the Al film upon its deposition and restrain degradation of EM resistance.

Second Embodiment

A structural cross-section of a second embodiment of the present invention is shown in FIG. **2**. An insulator layer **21** is first formed on an integrated circuit **20**. Next, a Ti film **22** and a TiN film **23** are respectively successively deposited on the insulator layer **21** as a barrier layer **28** with a thickness of about 30 nm and a thickness of about 20 nm. Further, a thin conductive film **24** having a thickness of about several tens of Å, which prevents penetration of nitrogen gas discharged from the TiN film **23** upon the subsequent formation of a conductive layer Al film **25**, is deposited on the barrier layer **28**. As the conductive film **24** for preventing the penetration of N_2, may preferably be used, for example, Al or Cu.

Next, the Al film **25** used as a conductive layer, is heated at about 225° C. in a manner similar to the first embodiment, so it is grown so as to range from 400 nm to 600 nm in thickness. Thereafter, an antireflection film (ARM) **26** relative to an Al surface based on a photolithography process for forming micro patterns is formed on the Al film **25** with a thickness of about 70 nm. Further, the so-formed film is subjected to a photolithography process and an etching process and then to patterning, whereby each of conductive layers is formed.

According to the second embodiment as described above, a TiN film is deposited and thereafter a thin conductive film for preventing penetration of N_2 is formed, whereby N_2 gas heated to a high temperature upon Al deposition and discharged from the surface of the TiN film and from within the TiN film is prevented from floating into an Al deposition chamber. Thus, it is possible to prevent N_2 from being mixed into the Al film upon its deposition and restrain degradation of EM resistance.

Third Embodiment

A structural cross-section of a third embodiment of the present invention is shown in FIG. **3**. An insulator layer **21** is first formed on an integrated circuit **20**. Next, a Ti film **22** and a TiN film **23** are respectively deposited on the insulator layer **21** as a barrier layer **28** with a thickness of about 30 nm and a thickness of about 20 nm. Further, a conductive film **27** having a film thickness of about a few tens Å, which nitrizes N_2 for itself and absorbs nitrogen gas, is deposited on the barrier **28**. As the conductive film **27**, which absorbs the N_2, may preferably be tantalum (Ta).

Next, an Al film **25** is deposited so as to range from 400 nm to 600 nm in thickness under a temperature of about 225° C. in a manner similar to the first embodiment. An antireflection film (ARM) **26** is grown thereon with a thickness of about 70 nm. Further, the so-formed film is subjected to a photolithography process and an etching process and then to patterning, whereby each of conductive layers is formed.

According to the third embodiment as described above, since a TiN film is deposited and thereafter such a thin conductive film as to nitrize and absorb N_2 for itself is formed, N_2 gas heated to a high temperature upon Al deposition and discharged from the surface of the TiN film and from within the TiN film is prevented from floating into an Al deposition chamber. Thus, it is possible to prevent N_2 from being mixed into the Al film upon its deposition and restrain degradation of EM resistance.

Fourth Embodiment

A process sectional view for describing a fourth embodiment of the present invention is shown in FIG. **4**. An insulator layer **31** is first formed on an integrated circuit **30**. Next, a Ti film **32** and a TiN film **33**, which serve as a barrier layer, are respectively successively deposited on the insulator layer **31** with a thickness of about 30 nm and a thickness of about 20 nm. Thereafter, a wafer is heated at about 350° C. corresponding to a temperature greater than or equal to a temperature for the deposition of a conductive layer Al film for 60 seconds or longer within a processing chamber in which the wafer is heated to a high temperature, thereby allowing N_2 gas to be released from the surface of

the TiN film and from within the TiN film. The result thereof is shown in FIG. **4**(*a*).

Thus, the TiN film results in a TIN film **33'** from which the N_2 gas is released. Thereafter, an Al film **34** is deposited on a barrier layer **36** formed with the TiN film **33'** on the Ti film **32** at a temperature of about 225° C. so as to range from 400 nm to 600 nm in thickness in a manner similar to the first embodiment. Since, at this time, the N_2 gas has already been released from the TiN film, N_2 can be prevented form being mixed into the Al film **34**. Afterwards, an antireflection (ARM) film **35** is deposited with a thickness of about 70 nm. The result thereof is shown in FIG. **4**(*b*). Further, the so-deposited film is subjected to a photolithography process and an etching process and then to patterning, whereby each of conductive layers is formed.

According to the fourth embodiment as described above, a TiN film is deposited and thereafter a wafer is heated to a temperature greater than or equal to an Al deposition temperature within a processing chamber in which the wafer is heated to a high temperature, thereby releasing N_2 gas from the TiN film in advance. Therefore, the N_2 gas discharged from the surface of the TiN film and from therewithin is reduced even if it is heated to the high temperature upon the Al deposition. Thus, it is possible to prevent N_2 from being mixed into the Al film upon its deposition and restrain degradation of EM resistance.

Fifth Embodiment

A structural section of a fifth embodiment of the present invention is shown in FIG. **5**. An insulator layer **41** is first formed on an integrated circuit **40**. Next, a Ti film **42** and a TiN film **43** are respectively successively deposited on the insulator layer **41** as a barrier **46** with a thickness of about 30 nm and a thickness of about 20 nm by using a multi-chamber sputtering apparatus. Now Ar is added to N_2 used as deposition gas to form TiN upon deposition of the TiN film **42** by a reactive sputter. If an additive flow ratio of Ar gas to N_2 gas is set to 50% or more, for example, then the release of N_2 is avoided in a subsequent Al film forming step. However, when the additive flow rate of the Ar gas increases excessively, the film will result in Ti other than TiN. Since a condition for the additive flow rate of the Ar gas, which allows the film to transition from the TiN to Ti, greatly varies depending on a growth condition, it is necessary to execute the above processing on a TiN film forming condition although the definition of the upper limit of the ratio of addition thereof by a numerical value is not described herein.

Next, an Al film **44** is deposited on the barrier layer **46** so as to range from 400 nm to 600 nm in thickness at a temperature of about 225° C. Next, an antireflection film (ARM) **45** is deposited thereon with a thickness of about 70 nm. Further, the so-deposited film is subjected to a photolithography process and an etching process and then to patterning, whereby each of conductive layers is formed.

According to the fifth embodiment as described above, since the ratio of quality of flow between the N_2 gas and the Ar gas is set to 50% or more as the condition under which the TiN films formed as the barrier layer are deposited, the concentration of N_2 discharged from the surface of the TiN film and from within the TiN film decreases. Further, the N_2 gas discharged from the surface of the TiN film and from therewithin is reduced even if it is heated to a high temperature upon Al deposition. Thus, it is possible to prevent N_2 from being mixed into the Al film upon its deposition and restrain degradation of EM resistance.

While the preferred embodiments of the semiconductor devices and the semiconductor device manufacturing methods according to the present invention have been described above with reference to the accompanying drawings, the present invention is not limited to such embodiments. It will be apparent to those skilled in the art that various changes or modifications can be supposed to be made to the invention within the scope of a technical idea described in the following claims. It should be understood that those changes or modifications fall within the technical scope of the present invention.

In the present application, no device claim is claimed. However, the following claims may be claimed in a separate application.

A semiconductor device having a multilayered conductive layer, comprises:

- an insulator layer formed on an integrated circuit;
- a barrier layer comprised of a first titanium film and a titanium nitride film whose surface layer portion is low in nitrogen concentration, said barrier layer being formed on the insulator layer;
- a second titanium film formed on the barrier layer; and
- an aluminum film used as a wired metal, which is formed on the second titanium film.

In the semiconductor device, the second titanium film may be a thin film which is about a few tens Å.

As another example, a semiconductor device having a multilayered conductive layer, comprises:

- an insulator layer formed on an integrated circuit;
- a barrier layer comprised of a titanium film and a titanium nitride film, which is formed on the insulator layer;
- a conductive film formed on the barrier layer, for preventing the discharge of nitrogen gas from the titanium nitride film; and
- an aluminum film used as a wired metal, which is formed on the conductive film.

In the semiconductor, the conductive film maybe a film for preventing penetration of the nitrogen gas.

In the semiconductor device, the conductive film may be formed of aluminum or copper.

In the semiconductor device, the conductive film may be a thin film that is about several tens of Å.

Further, in the semiconductor device, the conductive film may be a film that absorbs the nitrogen gas.

In the semiconductor device, the conductive film may be comprised of tantalum. The conductive film may be a thin film which is about a few tens Å.

According to the present invention as described above, since a method of forming a multilayered conductive layer avoids interference with the growth of grains due to the mixing of nitrogen gas discharged from a titanium nitride film in a barrier layer when aluminum used as a wired metal is formed by being heated at a temperature of 200° C. to 400° C., electromigration resistance can be improved and reliability of a semiconductor device can be enhanced.

What is claimed is:

1. A method of manufacturing a semiconductor device having a multilayered conductive layer, comprising:

- forming an insulator layer on an integrated circuit;
- forming a barrier layer comprised of a first titanium film and a titanium nitride film on the insulator layer;
- heat-treating the barrier layer to release nitrogen gas from the titanium nitride film;
- forming a second titanium film on the barrier layer after said heat-treating; and

forming an aluminum film used as a wired metal on the second titanium film.

2. A method of manufacturing a semiconductor device comprising:

providing a semiconductor substrate;

forming a barrier layer on the semiconductor substrate;

subjecting the barrier layer to a heat-treatment at a first temperature so that nitrogen gas is released from the barrier layer;

forming a nitrogen gas absorption layer on the barrier layer after the heat-treatment; and

after said forming a nitrogen gas absorption layer, forming a metal layer over the barrier layer at a second temperature that is equal to or lower than the first temperature.

3. A method of manufacturing a semiconductor device according to claim 2, wherein the formation of the barrier layer includes forming a first Ti layer on the semiconductor substrate and forming a TIN layer on the first Ti layer.

4. A method of manufacturing a semiconductor device according to claim 2, wherein the formation of the nitrogen gas absorption layer includes forming a second Ti layer on the barrier layer.

5. A method of manufacturing a semiconductor device according to claim 2, wherein the formation of the metal layer includes forming an Al layer on the nitrogen gas absorption layer.

6. A method of manufacturing a semiconductor device according to claim 2, wherein the second temperature is about 225° C.

7. A method of manufacturing a semiconductor device according to claim 2, wherein the first temperature is about 350° C.

8. A method of manufacturing a semiconductor device according to claim 2, further comprising forming an antireflection film on the metal layer.

9. A method of manufacturing a semiconductor device according to claim 8, wherein the formation of the antireflection film includes forming a TiN layer on the metal layer.

10. A method of manufacturing a semiconductor device comprising:

providing a semiconductor substrate;

forming a barrier layer on the semiconductor substrate;

subjecting the barrier layer to a heat-treatment at a first temperature so that nitrogen gas is released from the barrier layer;

forming a nitrogen gas prevention layer on the barrier layer after the heat treatment; and

forming a metal layer on the nitrogen gas prevention layer.

11. A method of manufacturing a semiconductor device according to claim 10, wherein the formation of the barrier layer includes forming a first Ti layer on the semiconductor substrate and forming a TIN layer on the first Ti layer.

12. A method of manufacturing a semiconductor device according to claim 10, wherein the nitrogen gas prevention layer includes Al or Cu.

13. A method of manufacturing a semiconductor device according to claim 10, wherein the formation of the metal layer includes forming an Al layer on the nitrogen gas prevention layer.

14. A method of manufacturing a semiconductor device according to claim 10, further comprising forming an antireflection film on the metal layer.

15. A method of manufacturing a semiconductor device according to claim 14, wherein the formation of the antireflection film includes forming a TiN layer on the metal layer.

* * * * *